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Jet Production in Muon Scattering at Fermilab E665

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ABSTRACT

Measurements of multi-jet production rates from Muon-Nucleon and Muon-Nuclei scattering at Fermilab-E665 are presented. Jet rates are defined by the JADE clustering algorithm. Rates in Muon-Nucleon deep-inelastic scattering are compared to Monte Carlo model predictions. Preliminary results from jet production on heavy targets, in the shadowing region, show a higher suppression of two-forward jets as compared to one-forward jet production.

1. Introduction

Jet production from muon scattering in a wide kinematic range and with several targets is explored at the Tevatron experiment 665. Values of Q^2 (four-momentum transfered) up to 25 $(GeV/c)^2$ are obtained in light targets (H and D) to explore the perturbative QCD regime.[1] These data can be used to study the structure (parton densities) and forces (strong coupling constant, α_s) inside the hadrons. In addition, very low values of x-Bjorken (x_{Bj}, down to 10^{-5}) are obtained, with the limitation of having low Q^2 values, to measure hadronic jet production from nuclear targets (C, Ca and Pb) in the shadowing region.[2] Shadowing is the term used to describe the observed phenomenon where the total cross section of a nuclear process is less than A (atomic number) times the respective single-nucleon process. Data on jet production in this regime can be used to study parton propagation and hadronization in nuclear matter.

The E665 collaboration[3] used an open geometry detector. Data were taken during the 1987-88 and 1990-91 Tevatron run periods on H, D, C, Ca, Xe and Pb targets using a muon beam of 490 GeV average energy. The following notation is used in this paper: Q^2 is the negative square of the virtual-photon four-momentum; W is the total hadronic center-of-mass energy and ν is the energy of the virtual-photon in the lab frame. E_{Beam} is the energy of the beam and M the mass of the nucleon.

Table 1: Identification Matrix

	Partonic level	
Hadronic level	*(1+1)* jets	*(2+1) jets*
(1+1) jets	68%	3.3%
(2+1) jets	20.3%	8.4%

2. Multi-jet Production on Nucleons

Data on Muon-Proton deep-inelastic scattering (DIS) are studied to test perturbative QCD. We study events with three jets in the final state, including the proton-remnant jet and two jets from the hard QCD interaction - the (2+1)-jet topology. Those events are produced, at leading-order, by gluon bremsstrahlung from the initial and final partonic states and by photon-gluon fusion.

Charged particles reconstructed in the forward spectrometer and neutral particles reconstructed in the electromagnetic calorimeter are used in the analysis. The event sample is defined using the following kinematical cuts: $4.0 \leq Q^2 \leq 25.0(GeV/c)^2$, $W \geq 20GeV$, $\nu \geq 40GeV$, $x_{Bj} = Q^2/2M\nu > 0.003$ and $0.05 \leq y_{Bj} = \nu/E_{Beam} \leq 0.95$. A calorimeter cut was used to remove coherent photon bremsstrahlung from the sample. Only particles going forward in the center-of-mass system are used in this analysis. All charged particles are considered to be pions and all neutrals particles to be photons.

To define the number of jets in an event the JADE algorithm[4] is used. The (2+1)-jet rates, $R_{(2+1)}$, are defined as the ratios between the number of (2+1)-jet events and the total number of events. The data distributions have been corrected bin by bin using a Monte Carlo simulation of the detector. We estimated the total systematic error coming from our ability to model the detector and from event and particle selection criteria to be less than $\Delta R_{(2+1)} = 0.03$.

Table 1 shows Monte Carlo comparisons between hadron level and partonic level jet rates defined by the JADE algorithm in our kinematic regime. We found an unacceptable number of misidentified events (off-diagonal elements on the table). This problem is caused by the inability of the JADE algorithm to identify real (1+1)-jets in events which have low momentum particles at high angles with respect to the virtual photon direction.

For identified (2+1)-jet events at the hadronic level, we calculate $< p_T^{jet} >$, averaging the two most forward jets. As seen in figure 1.a, the $< p_T^{jet} >$ distributions for

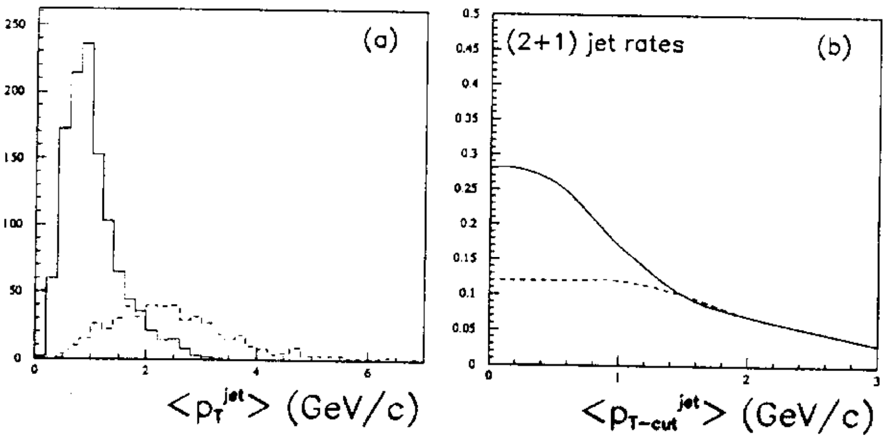

Figure 1: (a) $< p_T^{jet} >$ for identified (2+1)-jet events at the hadron level. Solid line is for misidentified jets [real (1+1)-jets] and the dashed line for real (2+1)-jet events. (b) (2+1)-jet rates versus $< p_{T-cut}^{jet} >$. Solid line at the hadron level and dashed line at the partonic level.

real and misidentified (2+1)-jets at the hadronic level are very different. Therefore, if we require a minimum $< p_T^{jet} >$ ($< p_{T-cut}^{jet} >$) in the sample, we will remove the misidentified events and we will improve the identification of real jets by the JADE algorithm. Figure 1.b shows how the matching between hadronic and partonic jet rates improve with increasing $< p_{T-cut}^{jet} >$. At about 2 GeV/c the matching between hadronic and partonic jet rates is very good (jet-parton duality).

We have investigated jet-parton duality among other variables associated with jets. The $< p_T^{jet} >$ and scaled invariant masses need to be rescaled between hadronic and partonic levels. The $< p_T^{jet} >$ at the hadronic level is in average 86% that of the partonic level jets. The scaled invariant masses are about 50% higher.

Figure 2 shows preliminary results for the (2+1)-jet rates from the E665 data at the hadron level versus Q^2 for a value of the JADE-jet resolution parameter, $y_{cut} = 0.06$ and $< p_T^{jet} > > 2GeV/c$ at the partonic level. Only statistical errors are shown. Also shown are the predictions of the (2+1)-jet rates at the parton level from various Lepto 6.1 Monte Carlo[5] options for $y_{cut} = 0.04$ and $< p_T^{jet} > > 2GeV/c$. The transformation between hadronic and partonic levels has been approximately taken into account by showing the hadronic jet rates for $y_{cut} = 0.06$ and partonic jet rates for $y_{cut} = 0.04$. After these corrections, we observe that the hadronic JADE-jet rates are similar to the Monte Carlo predictions of the ARIADNE[6] Lund version. However, they are higher than predictions based on PQCD matrix elements. The MRS(D^-)[7] set of parton distributions has been used for the predictions. Studies are underway to understand in more detail the connection between observed and partonic jet properties.

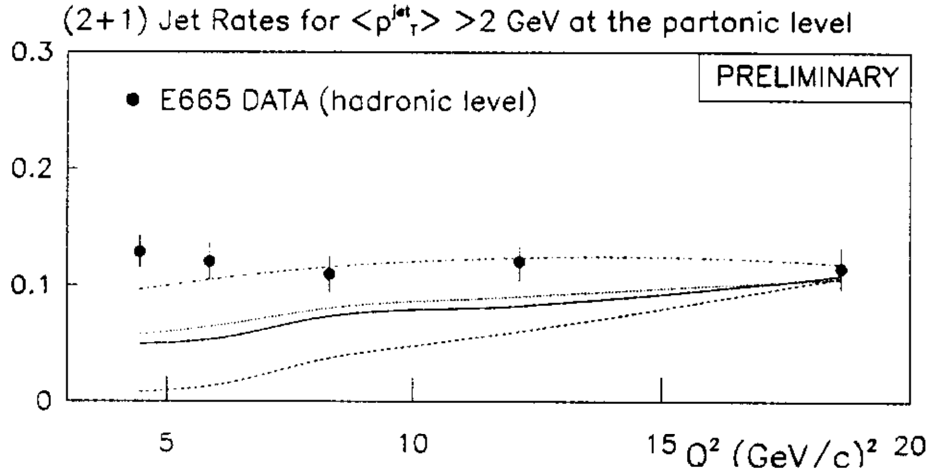

Figure 2: (2+1)-jet rates, at the hadron level, versus Q^2, for $y_{cut} = 0.06$ and $< p_T^{jet} > \, > 2GeV/c$ at the partonic level. Also shown are the predictions, at the parton level, from various Lepto 6.1 Monte Carlo options for $y_{cut} = 0.04$ and $< p_T^{jet} > \, > 2GeV/c$: Matrix Elements (ME) (solid), Parton Shower (PS) with default maximum virtuality (dashed), ME+PS (dotted) and Ariadne (CDM) (dotted-dashed).

3. Multi-jet Production on Nuclei

The JADE algorithm was also utilized to define forward di-jet production rates from C, Ca and Pb targets and these rates were compared to those from D in the kinematical region where shadowing has been observed in the total cross section. The following kinematical cuts are applied to the data: $Q^2 \geq 0.1GeV^2$, $\nu \geq 40GeV$, $x_{Bj} \geq 0.001$ and $0.05 \leq y_{Bj} \leq 0.75$. The electromagnetic calorimeter is used to remove the coherent and quasi-elastic $\mu\gamma$ backgrounds. Preliminary results from one third of the data are presented here.[8]

Figure 3 shows the (uncorrected) per nucleon cross section ($\sigma_A = \sigma/A$) ratios (for C/D, Ca/D and Pb/D) versus x_{Bj}, for events with 1+1 (one-forward) and 2+1 (two-forward) jets separately. All ratios show the clear signal of shadowing ($\sigma_A/\sigma_D < 1$) in the region $x_{Bj} < 10^{-2}$. The two-forward jet sample present a higher suppresion as compared to the one-forward jet sample. The data shown is uncorrected for acceptance, resolution and tracking inefficiencies. However, in order to reduce systematics, E665 rotated its targets every few minutes and therefore these corrections should cancel in the ratios. Detailed studies with the full data sample are underway.

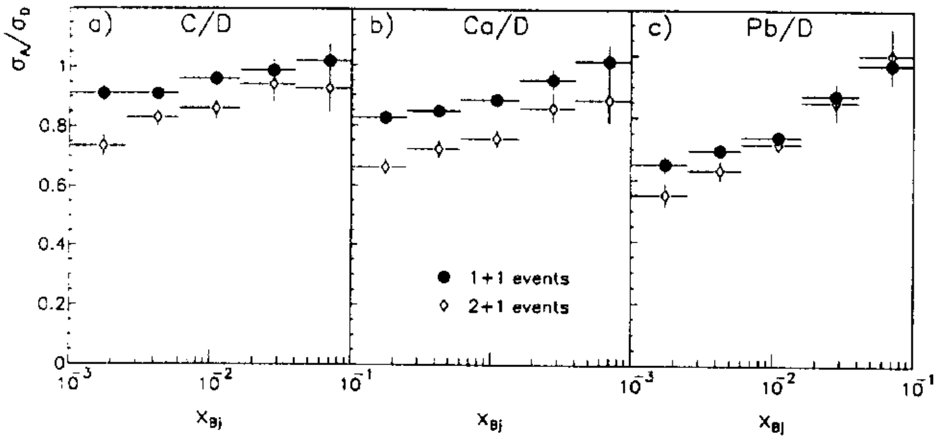

Figure 3: Per nucleon cross section ratios for events with 1+1 jets and 2+1 jets at $y_{cut} = 0.04$ versus x_{Bj} for C/D, Ca/D and Pb/D.

4. Conclusions

Multi-jet production rates have been measured in Muon-Nucleon and Muon-Nuclei scattering at Fermilab-E665. The JADE clustering algorithm is used to define jets. Preliminary results from the Muon-Proton sample show hadronic jet rates qualitatively similar to Lund Monte Carlo predictions at the partonic level, but only when jets with $< p_T^{jet} > > 2GeV/c$ and corrections from hadronization are considered.

Preliminary measurements of multi-jet events on nuclear targets in the shadowing region indicate a suppression of multi-jet events in heavy targets as compared to D. This suppresion is higher in the (2+1)-jet sample than the (1+1)-jet sample. These data may help us to investigate models of shadowing and the gluon distributions within the nuclei.

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